SECTION II.—GENERAL METEOROLOGY.

SOME TEMPERATURE CORRELATIONS IN THE UNITED STATES.

By THOMAS ARTHUR BLAIR, Observer.

[Dated: Weather Bureau, Salt Lake City, Utah, July 25, 1917.]

Introductory.

In recent years many meteorologists have noted the existence of characteristic seesaw variations in the weather at various widely separated places; an excess of temperature or precipitation in one part of the world occurs simultaneously with a deficiency in another part, or is followed after a definite interval by such deficiency. Most of the relations investigated have been seasonal, and it seems evident that they are connected with the more or less permanent areas of high and low pressure, which were named "centers of action" by Teisserenc de Bort, and that these in turn are affected by changes in the general circulation of the atmosphere induced by varying solar activity.

A recent paper by Craig [1] discusses such an inverse relation between the temperatures of Lower Egypt and southwestern England, and finds for the year a correlation coefficient of -0.43 ± 0.10, and for the first quarter of the year -0.72 ± 0.06. He determines the coefficients of correlation for various stations between Egypt and England with Cairo, and draws lines of equal correlation to fix the line where the relation changes from positive to negative. In addition to the theoretical bearing of such studies there is a popular interest in knowing to what extent an unusually dry or unusually cold period, for instance, in one section of the country is an indication of similar or of opposite conditions in other sections. In the present discussion the same method is employed in studying temperatures in the United States, and the following relationships are developed:

(1) There is a well-marked seesaw relation between the temperatures of southern California and of the southeastern United States for certain months of the year.

(2) For other months the temperatures vary independently.

(3) These changes in relationship are not wholly seasonal, but appear to have a wave-like oscillation in value.

(4) In consequence the coefficients expressing the annual temperature correlations have intermediate values.

(5) There is a definite daily correlation during the time of greatest monthly correlation.

January temperature relationships.

It is reasonable to expect that such interrelations would be most clearly defined in midwinter, when the contrasts between land and water temperatures and between tropical and extratropical temperatures are greatest. Accordingly in this paper the midwinter month of January is examined in most detail and is found to present the most marked relationships.

[1] *Craig, J. I.*, Seesaw of temperature between England and Egypt. Quart. Jour., Roy. met. soc., April 1915, 41: 89-98.

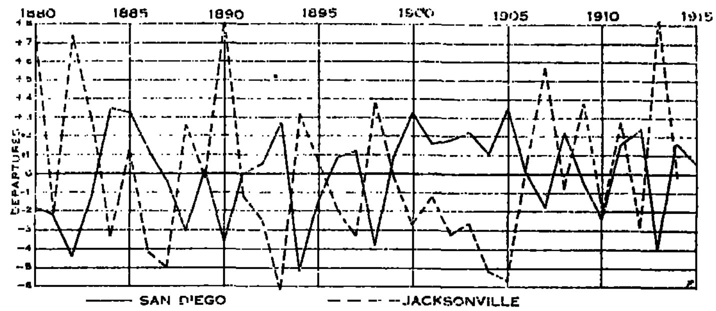

FIGURE 1.—Departures of the mean January temperatures from the normal, at San Diego, Cal., and Jacksonville, Fla., 1880-1914.

San Diego and other cities.—Considering first the January temperatures at San Diego, Cal., and Jacksonville, Fla., and using averages for the years 1880 to 1915, inclusive, we begin by plotting the departures, as shown in figure 1. This at once reveals a negative relationship between the two stations. The same data are presented in another form by the dot chart, figure 2. In this figure the abscissae of the dots, i. e., their distances to the right or left of the vertical line, are the departures from the mean at San Diego, and the ordinates, or distances above or below the horizontal line, are the departures at Jacksonville. It is apparent that a right diagonal through the second and fourth quadrants, represented by the equation $y = -x$, and corresponding to perfect negative correlation, would fit the facts fairly well. Since, at any rate, a straight line will evidently fit the conditions better than a curve of higher degree, let us assume the line to be represented by the general linear equation $y = a + bx$. Solving this for the most probable values of a and b, we get the equation $y = 0.04 - 1.16x$, represented by the line AB in figure 2. The solution is by the method of normal equations, developed in the theory of least squares, which will be briefly illustrated in Table 4, following.

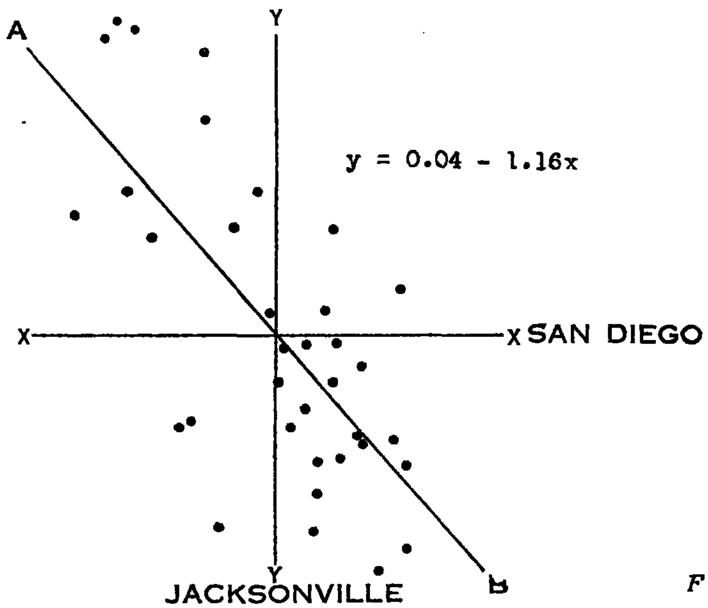

FIG. 2.—Dot chart of departures of the mean January temperatures from the normal, at San Diego (abscissae) and Jacksonville (ordinates).
Line A—B has equation: $y = 0.04 - 1.16x$.

This equation, with its constant term nearly equal to zero, and the coefficient of x nearly equal to 1, establishes a very definite relation between the January temperatures at San Diego and Jacksonville, but the most convenient expression of that relation is by means of a coefficient of correlation. In Table 1, which is the usual form of correlation table, familiar to readers of the REVIEW, the mean temperatures at the two stations are tabulated together with the departures, x and y, the squares of the departures, and the products of the departures. Using the equation,

$$r = \frac{\Sigma(xy)}{\sqrt{\Sigma x^2 \Sigma y^2}}$$

the coefficient of correlation, r, is found equal to $-0.707 \pm E_r$, signifying a rather high degree of negative correlation.

TABLE 1.—*Correlation of January temperatures between San Diego and Jacksonville, 1880 to 1915.*

Year.	San Diego, Cal.			Jacksonville, Fla.			xy
	Mean.	Departures. x	x^2	Mean.	Departures. y	y^2	
	°F.			°F.			
1880	52.8	−1.8	3.24	62.8	+7.4	54.76	−13.32
1881	52.5	−2.1	4.41	53.2	−2.2	4.84	+ 4.62
1882	50.3	−4.3	18.49	62.8	+7.4	54.76	−31.82
1883	53.6	−1.0	1.00	58.2	+2.8	7.84	− 2.80
1884	58.1	+3.5	12.25	52.0	−3.4	11.56	−11.90
1885	57.9	+3.3	10.89	56.7	+1.3	1.69	+ 4.29
1886	55.8	+1.2	1.44	51.3	−4.1	16.81	− 4.92
1887	54.2	−0.4	0.16	50.4	−5.0	25.00	+ 2.00
1888	51.5	−3.1	9.61	58.0	+2.6	6.76	− 8.06
1889	54.8	+0.2	0.04	55.2	−0.2	0.04	− 0.04
1890	51.0	−3.6	12.96	63.4	+8.0	64.00	−28.80
1891	54.6	0.0	0.00	54.2	−1.2	1.44	0.00
1892	55.1	+0.5	0.25	53.0	−2.4	5.76	− 1.20
1893	57.4	+2.8	7.84	49.2	−6.2	38.44	−17.36
1894	49.5	−5.1	26.01	58.6	+3.2	10.24	−16.32
1895	53.2	−1.4	1.96	56.1	+0.7	0.49	− 0.98
1896	55.5	+0.9	0.81	53.5	−1.9	3.61	− 1.71
1897	55.8	+1.2	1.44	52.1	−3.3	10.89	− 3.96
1898	50.8	−3.8	14.44	59.2	+3.8	14.44	−14.44
1899	55.5	+0.9	0.81	55.2	−0.2	0.04	− 0.18
1900	57.8	+3.2	10.24	52.7	−2.7	7.29	− 8.64
1901	56.2	+1.6	2.56	54.2	−1.2	1.44	− 1.92
1902	56.4	+1.8	3.24	52.2	−3.2	10.24	− 5.76
1903	56.8	+2.2	4.84	52.8	−2.6	6.76	− 5.72
1904	55.7	+1.1	1.21	50.3	−5.1	26.01	− 5.61
1905	58.1	+3.5	12.25	49.8	−5.6	31.36	−19.60
1906	54.6	0.0	0.00	56.0	+0.6	0.36	0.00
1907	52.8	−1.8	3.24	61.1	+5.7	32.49	−10.26
1908	56.9	+2.3	5.29	54.6	−0.8	0.64	− 1.84
1909	54.2	−0.4	0.16	59.2	+3.8	14.44	− 1.52
1910	52.2	−2.4	5.76	53.0	−2.4	5.76	+ 5.76
1911	56.2	+1.6	2.56	58.2	+2.8	7.84	+ 4.48
1912	57.0	+2.4	5.76	52.6	−2.8	7.84	− 6.72
1913	50.6	−4.0	16.00	63.6	+8.2	67.24	−32.80
1914	56.3	+1.7	2.89	55.2	−0.2	0.04	− 0.34
1915	55.2	+0.6	....	....	....	....	....
Sums	....	....	204.05	....	....	553.16	−237.39
Mean	54.6	....	....	55.4	....	....	....

$$r = \frac{\Sigma xy}{\sqrt{(\Sigma x^2)(\Sigma y^2)}} = \frac{-237.39}{\sqrt{204.05 \times 553.16}} = -0.707 \pm E_r$$

In the same manner, and using the same 36-year series, correlation coefficients were calculated for various other cities throughout the United States, comparing them in each case with San Diego. These values are entered on the chart, figure 3, and the lines of equal correlation drawn.

The temperature values used were taken, for the most part, from printed copies of local annual meteorological summaries. In a few of these the mean temperatures were recorded to whole degrees only, and there is thus some lack of uniformity, since for the greater number of stations used the temperatures and departures are recorded to tenths. It is to be noted, however, that any accidental errors or lack of homogeneity in the records will numerically lower the values of the coefficients rather than raise them. The means were computed to tenths of degrees only, but to whole degrees only where the original values were in whole degrees. This introduces a slight error, due to the fact that the mean is not expressed with complete accuracy. No correction was made for this error in the values of the coefficients as entered on figure 3, but corrections made in a few cases indicate that the error is not greater than 1 in the third decimal place, and hence is not significant.

Examining the chart, we find a line of zero correlation extending from Minnesota southwestward through Nebraska and Kansas to western Texas. Values are positive and increasing westward from this line to a maximum of 1.00 at the base of comparison, San Diego; but are negative and increase numerically, eastward, to a maximum of over 0.7 in northern Florida. All values of the correlation coefficient numerically greater than 0.5 are more than six times their probable errors, and hence there is less than one chance in 20,000 that the results are accidental. As the smaller values approach zero, there is an increasing probability that the results are due to chance but this is rendered less likely, in the present case, by the consistency of the results at the different stations, enabling fairly symmetrical lines to be drawn in close conformity with all the data. (Two exceptions are to be noted; the results at Boise and Miami, the latter a short record, are not consistent with adjacent values.)

This map seems, therefore, to establish definitely the existence of a well-marked interrelation of temperature changes between southern California and the region comprising the East Gulf and South Atlantic States, and extending also into the Ohio Valley, but best developed in northern Florida.

Los Angeles and other cities.—It will be observed that the area of evident negative correlation is greater than that of well-defined positive correspondence with San Diego. The +0.5 line includes only Nevada, western Arizona, and that portion of California south of San Francisco. The relation of Los Angeles to San Diego is not quite as close as might be expected, while San Francisco is surprisingly divergent. Knowing that a certain January was warmer than the average at San Diego, we can assume that it was also warmer at Winnemucca and Salt Lake City with greater probability than we can make the same assumption for San Francisco. With still greater probability we can assume that it was a cold January in all the Southern States east of the Mississippi River. In order to test still further the reliability of these results, and especially their independence of the San Diego record, Los Angeles departures were used as the basis for the computation of correlation coefficients with several of the southern cities. The values are given in the accompanying Table 2, together with those for December and February. It thus appears that the relation holds about equally well for Los Angeles and for San Diego; and though more clearly exhibited in January, exists in February also.

TABLE 2.—*Coefficients of correlation of certain mean monthly temperatures at Los Angeles with stations in southeastern United States, 1880 to 1915, inclusive.*

Months.	Atlanta, Ga.	Galveston, Tex.	Jacksonville, Fla.	Key West, Fla.	Little Rock, Ark.	New Orleans La.	Norfolk, Va.	Pensacola, Fla.	Tampa, Fla.
	r.	r.	r.	r.	r.	r.	r.	r.	r.
December	+0.085	....	−0.386	....	....	....	....	−0.245	−0.335
January	−0.570	−0.417	−0.707	−0.658	−0.345	−0.592	−0.427	−0.654	−0.631
February	−0.450	....	−0.566	....	....	....	....	−0.576	−0.488

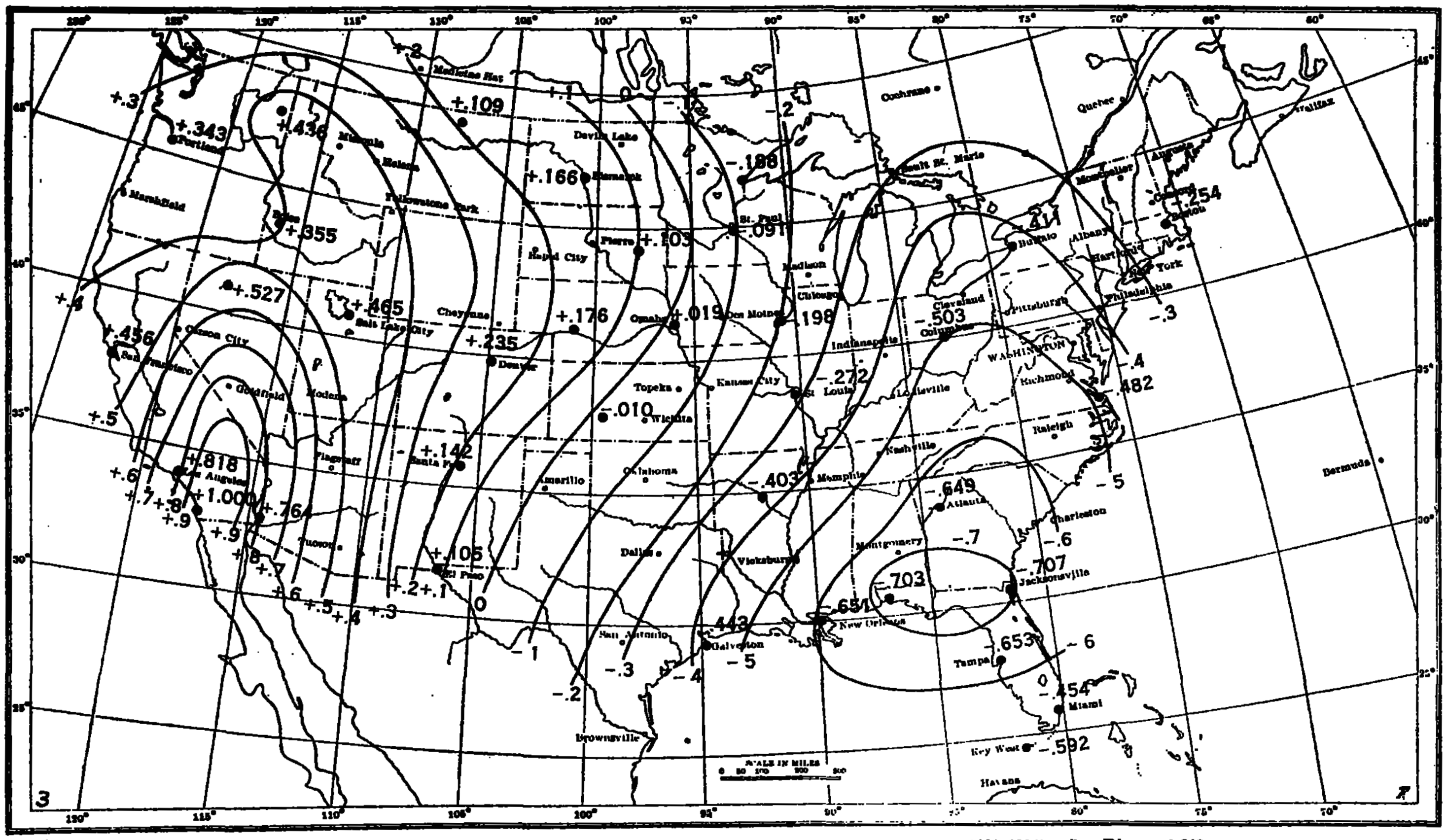

FIG. 3.—Isocorrelational chart of the United States for January mean temperatures (1880-1914). San Diego = 1.000.

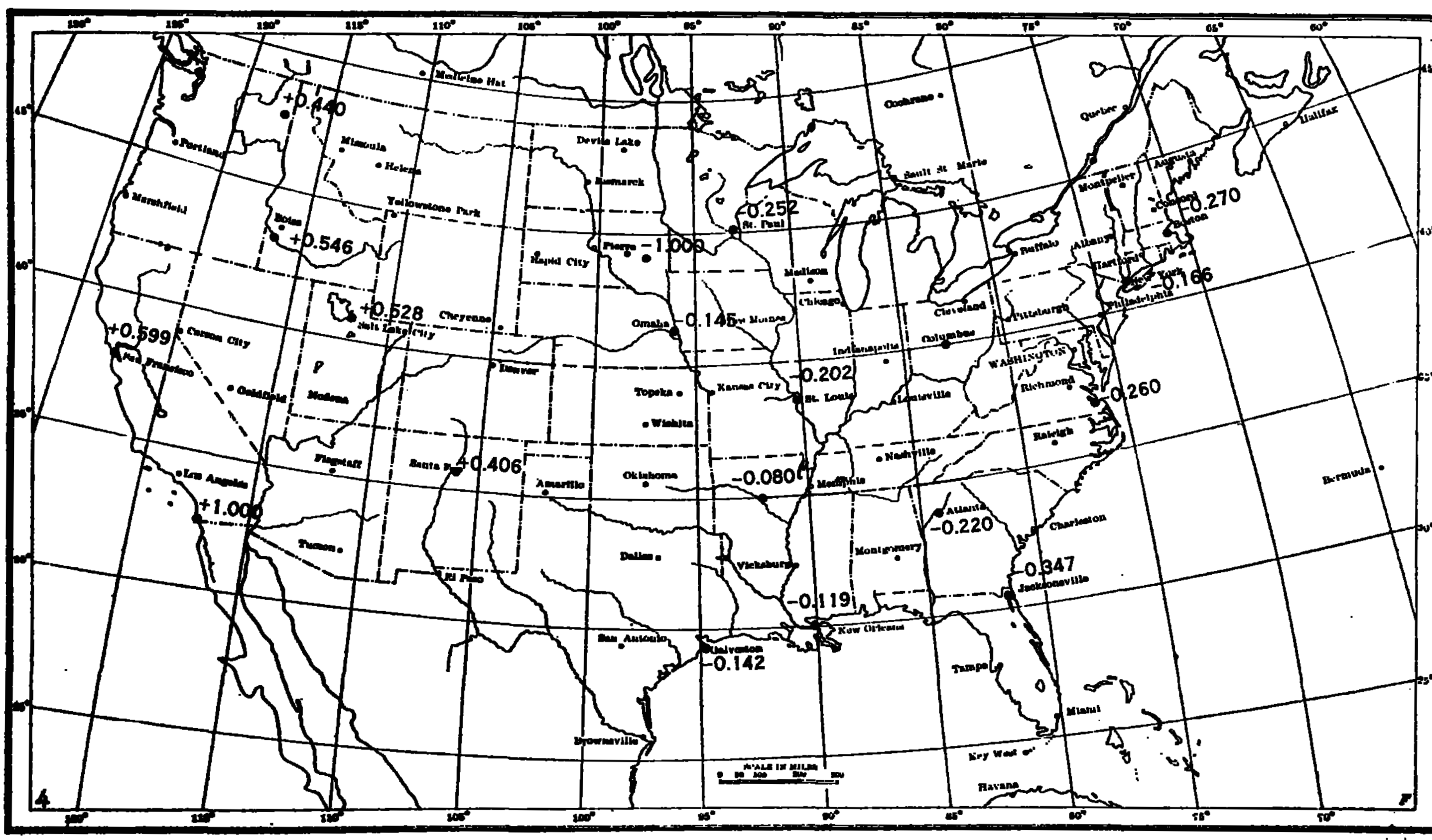

FIG. 4.—Correlational chart of the United States for mean annual temperatures (1880-1915). San Diego = 1.000.

Mean annual temperature relations.

Having shown in some detail the character of the correspondence in January, it is necessary to extend the inquiry to other months and to the year in order to determine the nature of the relationship—whether permanent or periodic. For this purpose, I have correlated the mean annual temperatures of San Diego and various other points in the United States in the same manner and for the same period as was done for January, with the results shown in the chart, figure 4. It will be noted that the country is divided between positive and negative correlation for the mean annual temperatures in about the same manner as for January; that the positive coefficients are in every case larger; but the negative ones are generally smaller. Moreover, the negative coefficients are not so consistently distributed geographically with reference to magnitude, and in no case does a coefficient attain the standard of safety, i. e., six times its probable error. The probable error for Jacksonville is ±0.099, and for Columbus, ±0.096. However, the results taken together leave little doubt of some inverse relationship.

Arctowski [3] has discussed the distribution of temperature changes in detail for the period 1900 to 1909, using annual means made up of the means of every 12 consecutive months, thus making a series of 109 values for the 10 years. Using the same period and the same method of "successive means," I have found the following annual correlations with San Diego:

Jacksonville, Fla.........	−0.371 ± 0.054
Columbus, Ohio...........	−0.459 ± 0.051
Omaha, Nebr..............	−0.204 ± 0.060
Salt Lake City, Utah....	+0.437 ± 0.052

These, while of about the same magnitude as those shown in figure 4, are, on account of the greater number of values used, well beyond the probability of chance results and confirm the conclusion that there is a permanent annual connection, which, however, is not so close as the January relationship.

Monthly temperature relations.

Let us now go a step farther and examine more closely the nature of this relation. Table 3 and figure 5 give the coefficients of correlation between San Diego and the four eastern stations Atlanta, Boston, Columbus, and Jacksonville, for each month separately.

TABLE 3.—*Coefficients of correlation of mean monthly temperatures at San Diego, with stations in eastern United States, for period 1880 to 1915, inclusive.*

Month.	Atlanta, Ga.	Boston, Mass.	Columbus, Ohio.	Jacksonville, Fla.	Mean.
	r	r	r	r	r
January	−0.649	−0.254	−0.503	−0.704	−0.528
February	− .450	− .270	− .428	− .484	− .408
March	− .324	− .215	− .281	− .514	− .338
April	−0.121	+0.008	−0.246	−0.129	−0.122
May	− .301	− .218	− .056	− .146	− .180
June	− .003	− .187	+ .035	+ .280	+ .031
July	−0.005	−0.252	−0.284	+0.056	−0.121
August	− .353	+ .051	− .411	− .126	− .210
September	− .082	− .177	− .148	− .134	− .135
October	−0.483	−0.197	−0.437	−0.349	−0.366
November	+ .010	+ .058	+ .085	− .058	+ .024
December	+ .085	− .135	+ .065	− .141	− .032
Year	−0.220	−0.270	−0.376	−0.347	−0.303

[3] *Arctowski, Henryk.* Study of the changes in the distribution of temperature in Europe and North America during the years 1900 to 1909. Annals, New York acad. sci., 27 June, 1914, 24: 39-113.

The lower curve of figure 5 represents the average values of the coefficients at the four stations, by months. An examination of these results will lead to the conclusion that

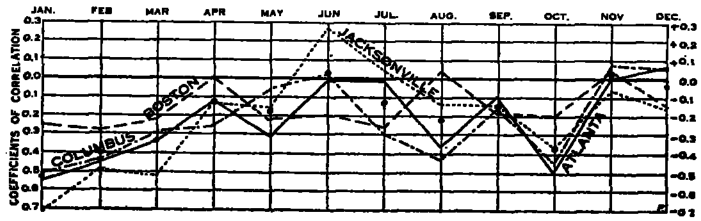

FIG. 5.—Correlations of mean monthly temperatures at San Diego, Cal., (1880-1915) with those of stations in the eastern United States for the same period.
—— Atlanta, Ga. — — — — Boston, Mass.
- - - - Jacksonville, Fla. —.—.—. Columbus, Ohio.
* * * * Mean of the four.

the annual correlation just proven is not, after all, a permanent relation persisting through the year, but is the result of a large correlation in some months, combined with no relation, or even a positive one in other months. It was probably to be expected that the summer months would show a less marked connection; certainly we do find the coefficients small from April to September, inclusive, with a slight positive coefficient for the average of the June results. But the most interesting part of the curves is in October, November, and December. There is a marked increase in the negative coefficient in October followed by a marked decrease to practically zero in November and December. We are safe in stating that there is no linear relation between the monthly temperatures of San Diego and these eastern stations in November and December; but there is a distinct negative relation in October and also in January and February. There is evidence throughout the year of this wave-like alternation in the values of the coefficients, but the period of the waves seems to vary at different seasons of the year, and probably does not in any case coincide exactly with the calendar months.

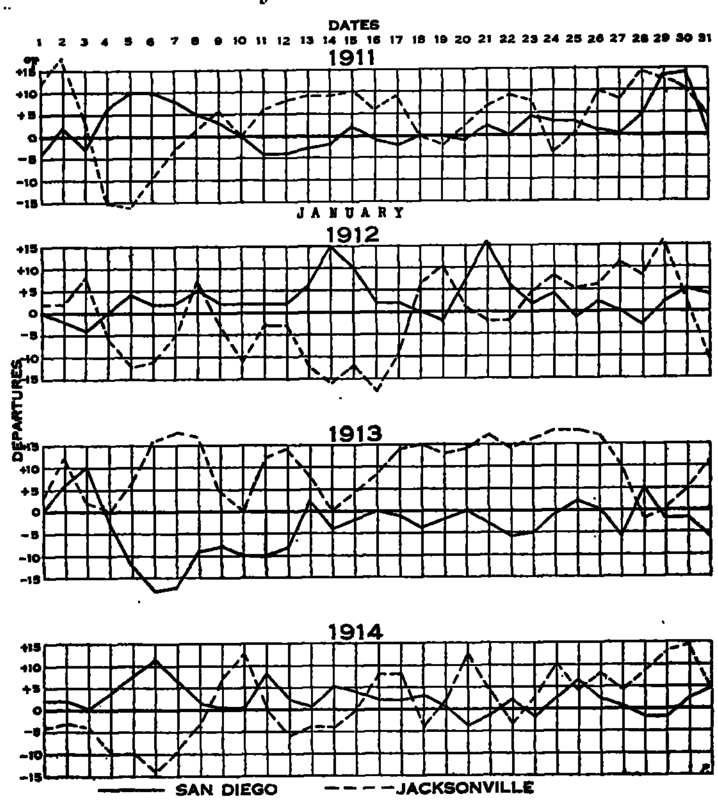

FIG. 6.—Departures of the daily mean temperatures in January at San Diego, Cal., and at Jacksonville, Fla., from the respective normals, during the years 1911-1914, inclusive.

There is still another relationship which naturally suggests itself in this connection. Does the negative correlation which exists in the January mean temperatures appear also from day to day in the daily means? Figure 6 presents the daily departures from the normal at San Diego and Jacksonville for the years 1911, 1912, 1913, and 1914, and the same data appear in the dot chart of figure 7. The values were computed from the daily maxima and minima as published in the several issues of the MONTHLY WEATHER REVIEW. These curves show clearly the same negative relation for corresponding days found characteristic of the months, subject, however, to more frequent exceptions. In Table 4, the daily departures for 1911 are tabulated, and the method of calculating the "line of best fit" is there indicated.[3]

Similar computations were made for 1912, 1913, and 1914, and the four equations derived are as follows:

For 1911, $y = 5.41 - 0.502x$

1912, $y = 1.31 - 0.867x$

1913, $y = 8.66 - 0.331x$

1914, $y = 4.34 - 1.37x$

The corresponding lines are shown in figure 7. Combining the four years into one, we get the equation,

$$y = 4.32 - 0.815x$$

and the line AB, figure 7.

TABLE 4.—*Departures in January, 1911, of the daily mean temperatures from the normal at San Diego, Cal., and Jacksonville, Fla.*

Date.	Departures. San Diego, x	Departures. Jacksonville, y	x^2	xy
1911.	°F.	°F.		
Jan. 1	− 4	+12	16	− 48
2	+ 2	+18	4	+ 36
3	− 3	+ 4	9	− 12
4	+ 6	−15	36	− 90
5	+10	−16	100	−160
6	+10	− 9	100	− 90
7	+ 8	− 3	64	− 24
8	+ 5	+ 1	25	+ 5
9	+ 3	+ 6	9	+ 18
10	0	0	0	0
11	− 4	+ 6	16	− 24
12	− 4	+ 8	16	− 32
13	− 3	+ 9	9	− 27
14	− 2	+ 9	4	− 18
15	+ 2	+10	4	+ 20
16	− 1	+ 6	1	− 6
17	− 2	+ 9	4	− 18
18	0	0	0	0
19	0	− 2	0	0
20	− 1	+ 2	1	− 2
21	+ 2	+ 7	4	+ 14
22	0	+ 9	0	0
23	+ 4	+ 8	16	+ 32
24	+ 3	− 4	9	− 12
25	+ 3	0	9	0
26	+ 1	+10	1	+ 10
27	0	+ 8	0	0
28	+ 4	+14	16	+ 56
29	+13	+13	169	+169
30	+14	+10	196	+140
31	+ 1	+ 4	1	+ 4
Sums (n=31)	+67	+134	839	− 59

COMPUTATIONS.

$\Sigma x = 67.$

$(\Sigma x)^2 = 4489.$

$\Sigma y = 134.$

$\Sigma x^2 = 839.$

$\Sigma xy = -59.$

$(\Sigma x)(\Sigma y) = 8978.$

$n(\Sigma x^2) = 26009.$

$n(\Sigma xy) = -1829.$

$$b = \frac{n(\Sigma xy) - (\Sigma x)(\Sigma y)}{n(\Sigma x^2) - (\Sigma x)^2} = \frac{-1829 - 8978}{26009 - 4489} = \frac{-10807}{21520} = -0.502$$

$$a = \frac{\Sigma y - b(\Sigma x)}{n} = \frac{134 + 33.634}{31} = \frac{167.634}{31} = 5.41$$

$$y = a + bx = 5.41 - 0.502x$$

[3] For a fuller exposition of the method see "Elementary Notes on Least Squares, etc.," by *C. F. Marvin*. MONTHLY WEATHER REVIEW, October 1916, 44:561-569.

This result was obtained by comparing corresponding days at the two stations, but there is evidence in figure 6 of a lag of one day at Jacksonville. Accordingly, figure 8 was constructed, comparing departures at San Diego with those of Jacksonville on the following day, for the same four years. The resulting figure is very similar, and the resulting equation almost identical, viz,

$$y = 4.35 - 0.829x.$$

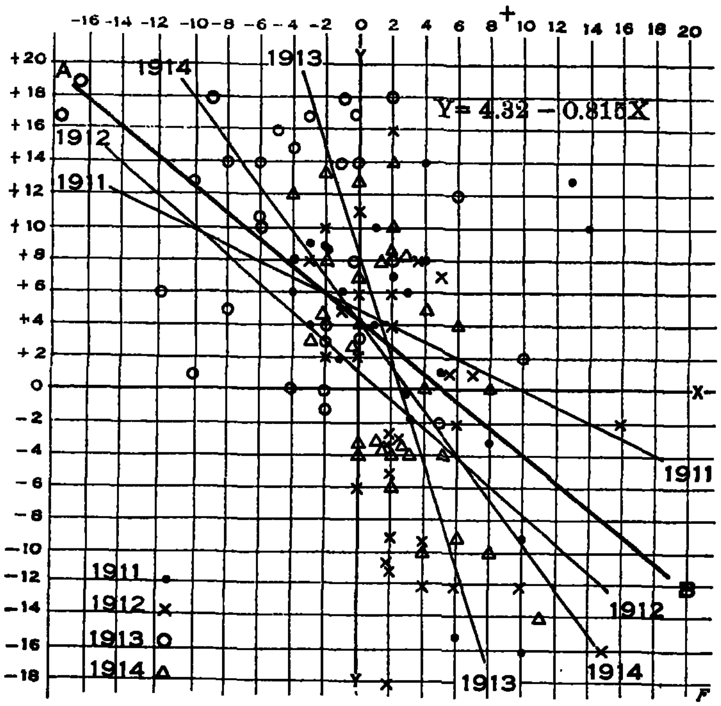

FIG. 7.—Dot chart of departures from the normal, of the daily mean temperatures at San Diego (abscissae) and at Jacksonville (ordinates). Lines of best fit are shown for each year and for the four years combined (A-B). Line A-B has the equation: $y = 4.32 - 0.815x$.

It will be noted that the lines AB in figures 7 and 8 do not appear to be placed properly for best fit. This frequently happens in constructing such charts, and illustrates the unreliability of the eye in such matters. It is probable that the eye fails to give proper weight to the more distant and scattered dots.

In these two equations and the accompanying figures, the departures were obtained by using the daily normals given in Weather Bureau Bulletin R, instead of the means of the period under discussion. These latter are 55° for San Diego and 57° for Jacksonville, greater in each case than the normals given in Bulletin R. Hence there is a preponderance of positive departures at both stations in figures 7 and 8, and the line of best fit is at some distance from the origin along the positive segments of both axes. This use of the normals better represents the meteorological conditions, but is not adapted to the computation of standard deviations or correlation coefficients. Using the actual means of the 124 days' record, we obtain the equation,

$$y = 0.267 - 0.828x,$$

when departures for the same days are compared; and

$$y = 0.274 - 0.816x,$$

when departures at San Diego are compared with those of the following day at Jacksonville. The result of this is merely to move the lines nearer the origin, keeping them practically parallel with themselves. That is, the lines represented by this calculation, but not drawn, have nearly the same slopes as those in figures 7 and 8, respectively. The coefficients of x in these equations express the slopes of the lines, and the slight differences, amounting in the second case to a difference in slope of 0.6°, are due to the fact that at Jacksonville the daily normals are not the same for the whole month, but vary from 53° to 55°. The correlation coefficients in these two cases are −0.507 and −0.500, respectively, which are more than ten times their probable errors. By actually counting and comparing the individual departures for the periods under discussion, we may express the relationships in percentages, as follows: (1) The departures of the January mean at San Diego and Jacksonville are of opposite sign 86 per cent of the time. (2) The daily departures during January, comparing the same days, are either zero or of opposite sign 77 per cent of the time. (3) The daily departures, allowing a lag of one day at Jacksonville, are either zero or of opposite sign 74 per cent of the time. A

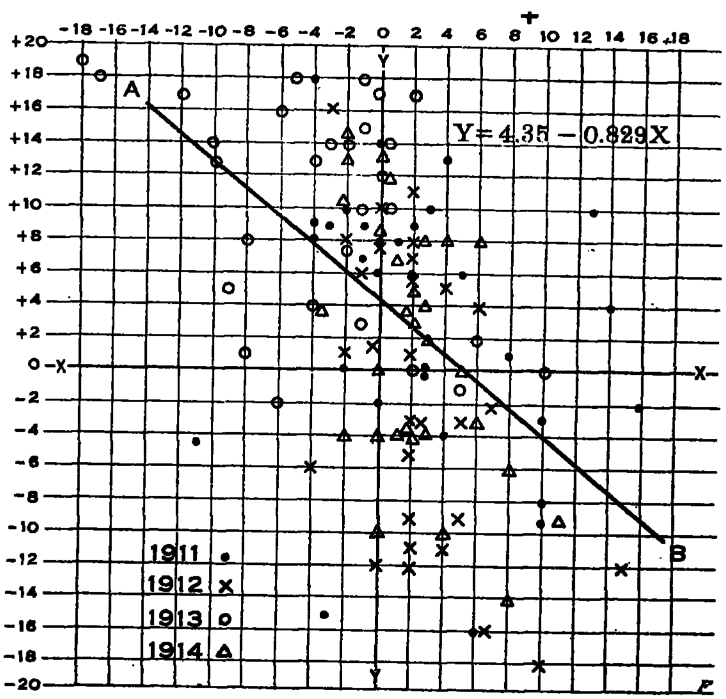

FIG. 8.—Dot chart of departures of the daily mean temperatures at San Diego, Cal. (abscissae) with those for the following day at Jacksonville, Fla. (ordinates), for the years 1911, 1912, 1913, 1914; and the line of best fit for the whole four years (A-B). Line A-B has the equation: $y=4.35-0.829x$.

fairly accurate forecast of the temperature at Jacksonville for any particular day could be made from the temperature at San Diego on the preceding day. We may conclude, I think, that the causes which produce opposite temperature changes at San Diego and Jacksonville, shown in the monthly and even in the annual means, affect the two stations almost simultaneously, being probably a little later, but less than 24 hours later, at Jacksonville.

The intention of this paper being merely to present the facts of these correlations, rather than give adequate explanations of them, no attempt has been made to correlate temperature changes with variations in pressure or solar radiation. However, a brief examination of the January and February isobaric charts, as published in the MONTHLY WEATHER REVIEW, indicates that the interior winter HIGH of the western United States is the connecting link between the temperatures of these widely separated areas. When the center of the HIGH is far westward, over Utah and Nevada, southern California is cold with northerly winds from the interior, and, at the same time, this westward shifting of the HIGH leaves the middle Mississippi Valley with relatively low pressure, inducing onshore warm winds on the South Atlantic and Gulf coasts. A shifting of the high pressure area eastward to the eastern slope of the Rocky Mountains produces cold continental winds in the southern States, and permits the movement of LOWS down the Pacific coast, causing warm southerly and westerly winds in southern California. This in brief is what seems to be indicated by the pressure charts. In this connection it will be remembered that Humphreys[5] has shown that the winter temperatures of the eastern United States are intimately connected with the presence or absence of a western Atlantic high area in the vicinity of the Bermudas. When this disappears or shifts far to the eastward, the eastern United States is cold on account of continental winds. This eastward movement appears to be accompanied by a similar movement in the "Rocky Mountain HIGH," thus contributing to the same cause, especially in the southeastern United States, the northern portion of the country being influenced by barometric changes that pass to the north of the high belt. Conversely, Humphreys also shows that the eastern coast is warm in winter when there is a well-developed HIGH in the western Atlantic; the present study discloses the same condition when the "Rocky Mountain HIGH" moves westward, thus again indicating a synchronous movement of these crests in the belt of high pressure. The permanent "Pacific HIGH," west of southern California, should also be studied in this connection if data were available. Such shiftings of pressure seem to be the immediate cause of the temperature relationships here discussed. * * *

Arctowski, in the study above cited, finds that there are persistent areas of positive and negative temperature departures whose movements are correlated, and that in North America these displacements seem to be confined to the continent, so that in consequence they pendulate from one side to the other. He says that these changes occur "seemingly in correlation with the equatorial temperature changes" and that a center exists in New Mexico, Arizona, and southern California "where the variation displays a striking preference to belong to the inverse type, and that, on the contrary, in Pennsylvania and Oregon the direct type is predominant." The results of the correlations herein discussed are in general agreement with these conclusions, and by arriving at the results in a different way furnish confirmation thereof.

There remains, however, the oscillation in the values of the monthly coefficients of correlation to be explained. Clayton[6] observes that the changes are analogous to a series of waves, and that there is an indication that even for the same station the coefficient of correlation with solar change will be positive for a time, and then negative for a time, with a sharp change between the two. The monthly correlations here presented completely confirm this view, with the important addition that the sharp reversals in relation occur at the same time in successive years. This is shown by the fact that temperatures at San Diego and Jacksonville have varied oppositely in October and also in January and February for a 36-year period, while in November and December they have varied quite independently. It is to be noted especially that these changes in relation are not changes with the

[5] *W. J. Humphreys*, Why some winters are warm and others cold in the eastern United States. MONTHLY WEATHER REVIEW, December, 1914, 42:672–675.

[6] *Clayton, H. Helm*. Effects of short-period variations in solar radiation on the earth's atmosphere; *in* Smithsonian misc. coll., May, 1917. v. 68, no. 3.

advancing seasons, but seem to be true oscillations whose corresponding phases occur at the same time each year. A complete explanation of this phenomenon will doubtless await a long and detailed analysis of the complex changes in the distribution of temperature and pressure over the globe resulting from seasonal changes and from changes in solar radiation.

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RAINFALL AND GUNFIRE.[1]

By ALFRED ANGOT, Director,
Bureau Central Météorologique de France.

[*Review reprinted from* Nature, London, Aug. 9, 1917, 99:467-8.]

M. Angot, the eminent director of the French Meteorological Service, has made a valuable and authoritative contribution, published in the journal of the French Academy of Agriculture for May, to the literature of a well-worn controversy.[1] The alleged connection between rainfall and gunfire, in favor of which so many champions sprang up during the wet periods of 1914–1916, has recently lost favor as a subject for argument, owing, no doubt, to the coincidence of the Spring drought of 1917 with the Allied offensive on the western front; but so short is the public memory, especially for negative evidence, that the incidence of 3 inches of rain during a recent summer afternoon in London, N. W., has proved sufficient to disinter the bone of contention [below p. 453]. The mental attitude of the public toward a theory of this nature is of great psychological interest: there is little doubt that, should we experience this summer [1917] a repetition of the weather of July, 1888, when snow fell in London, followed by a recurrence of that of August, 1911, when the thermometer touched 100°F. at Greenwich, both phenomena would generally be attributed to the war.

Accordingly M. Angot's paper reaches us at an opportune moment. After dealing briefly with the historical aspect of the question, and alluding to the work of M. Le Maout—who, not content with having established a connection between the bombardments of the Crimean War and the rainfall of India, the United States, Nicaragua, and Barbados, went on to ascribe the diurnal variation of the barometer to the striking of public clocks and the ringing of church bells—M. Angot proceeds to consider the physical changes which could be effected by the discharge of artillery, and could at the same time be held responsible for the causation, increase, or acceleration of rainfall.

The first proposition is that a succession of violent explosions might result in the displacement of masses of cold air at certain heights, which, coming under the influence of the upper winds and encountering layers of warmer, saturated air, could give rise to precipitation which would not otherwise have occurred: in this connection the author points out that in order to obtain a rainfall of so small an order as 1 mm. (0.04 in.), even if one were to take two equal masses of saturated air, the one at a temperature of 0° C., the other at 20° C. (an extreme case, of course), it would be necessary to effect a rapid and thorough intermingling of the two throughout a layer of air 6,850 meters in thickness. In M. Angot's opinion, the mixing of layers of air may be the cause of cloud formation or of slight drizzle at the earth's surface, but can never be responsible for considerable precipitation.

In the case of the second proposition—that water vapor resulting from chemical reaction of the explosives might take effect—it is asserted that in order to produce the same amount of rainfall (1 mm.) as in the previous proposition, the employment of no fewer than 21,750 tons of melinite per square mile would be necessitated—that, indeed, only on the supposition that all the hydrogen in the explosive became water vapor, which condensed immediately in its entirety and, so to speak, on the spot.

In the third and last instance, the possibility of electrical action being brought into play is considered in some detail. We know that supersaturated air (i. e., air which contains more water vapor than it normally should be able to hold for the existing temperature) is a physical possibility, in the absence of dust particles or other matter which may form nuclei for condensation. The necessary medium may be supplied by the action of ozone, of ultraviolet rays, by any cause, in fact, which can set up ionization of the atmosphere; under this last category may be classed the detonation of high explosives, inasmuch as highly ionized gases result therefrom. The lower regions of the atmosphere, however, which alone are the seat of explosive activity on a large scale, always harbor large numbers of both ions and dust particles, and can not, therefore, be subject to supersaturation; while it has yet to be shown that the addition of quantities of ions or of dust particles to a stratum of atmosphere nearly, but not quite, saturated can bring about premature condensation. Assuming for the moment the possibility of such a hypothesis, we must consider that no outpouring of ions or dust particles can do more than accelerate a precipitation which would be necessitated sooner or later by the progressive cooling of the air, since the mass of water that results from the cooling of, say, a kilogram of saturated air from 15° C. to 0° C. is constant (rather more than 5 grams), whether or not supersaturation may have existed at the inception of the temperature reduction.

Having thus pronounced upon the theories which have been advanced to account for the alleged connection, M. Angot goes on to consider whether in reality anything has occurred that needs accounting for—whether the rainfall since the outbreak of hostilities has been less inclined to observe the rules by which we endeavor to forecast its occurrence than before. Careful comparison between the daily weather maps and the observed rainfall figures has convinced him that it is not. He points out, very rightly, that we have been passing through a series of wet years since 1909—a period that balances the run of dry years 1898–1904 (1903 and 1911 were both exceptions to their groups and may be said to balance each other)—and that excess of rain in 1915 and 1916 might reasonably have been expected; that 1909 was wetter (in France) than 1915; 1910 than 1916; furthermore, that during December, 1915, an unprecedentedly wet month, relative calm prevailed over the whole front, and that in the second 10-day period of the very wet February of 1916, considerably more rain fell (40 mm. as against 28 mm.) than in the last 10-day period, which witnessed the development of the giant German bid for Verdun. Similar conclusions will be reached if frequency of rain instead of amount be considered: 1910 had more rain-days than 1916; 1912 and 1913 both had more than 1915, when the number in France was 11 below the average. The author has found nothing exceptional in the local distribution of rainfall: proximity to the firing zone has not resulted in relatively greater

[1] *Angot, Alfred.* Le canon et la pluie. Comptes rendus, Acad. d'agric. (France), No. 18, 1917, 3: 501-506.